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THE DEVELOPMENT OF A METHOD AND APPARATUS FOR THE STUDY OF ROLLING RESISTANCE OF ELECTRIC STREET CARS

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THE DEVELOPMENT OF A METHOD AND APPARATUS FOR THE STUDY OF ROLLING RESISTANCE OF ELECTRIC STREET CARS

BY

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and

ERNST LEOPOLD PFLANZ

A Thesis Submitted for the Degree of

BACHELOR OR SCIENCE

CIVIL ENGINEERING COURSE

UNIVERSITY OF WISCONSIN

1911

INTRODUCTION.

The importance of the study of train resistance has long been realized in the economic operation of steam railroads; but it is only in comparatively recent years that this subject is being considered in electric railway operation. This is probably due to the electric lines no longer being satisfied with purely passenger traffic, but trying also to handle freight traffic. The amount of the latter that can be handled most economically depends upon the ruling and maximum grades, and these again, to a certain extent, depend on the rolling resistance of the train. Consequently, any tests that will lead to the more accurate determination of these resistances, and to the intelligent reduction of grades, will aid in the proper expenditure of money for the construction of new lines and the revision of old ones.

For this purpose, then, various tests and experiments have been made along these lines, but most of them were for only local use and the methods used were not of the best. Appreciable errors crept in as a result. The largest number of tests for train resistance has

been made on steam roads and these tests usually were made by placing a dynamometer car between the locomotive and the body of the train. The coupler between the car and the locomotive includes a dynamometer attachment which automatically records the actual pull on the drawbar at any instant. Apparently this ought to solve the problem very easily and accurately; but in practice it is found that the interpretation of the dynamometer records is not easy and they are liable to be misconstrued. One of the practical difficulties is to determine the actual velocity, especially when the velocity is not regular. Speed recorders are supposed to indicate the velocity at any instant, but they are not very accurate, even when the speed is uniform. When the velocity of the train is decreasing, the kinetic energy of the train is being turned into work and the force transmitted through the dynamometer is less than the amount of the resistance which is actually overcome. Similarly, when the velocity is increasing, the force indicated is larger than is required to overcome the resistance, but the excess is being stored up as kinetic energy.

On electric railway cars many tests have also been made with electric dynamometer cars or by measurement of input, output and speed.

But no matter what method is used, the important factor in all these tests, as will be seen later, is the accurate determination of the velocity. In none of the tests performed up to this time has this been done satisfactorily. In carrying out the following work, the object sought for most, has been the development of a method and apparatus whereby all the factors can be measured accurately. This necessitated the construction of apparatus strong enough to withstand the blows of the car-wheel at high velocities, and yet of sufficient delicacy to respond instantly and not to impede in any way the progress of the car.

Method.

The method to be used with the apparatus is what is known as a "drop test" or "drifting test", as performed by A. M. Wellington in the late '70's; starting cars from a state of rest down a known grade and deduc-

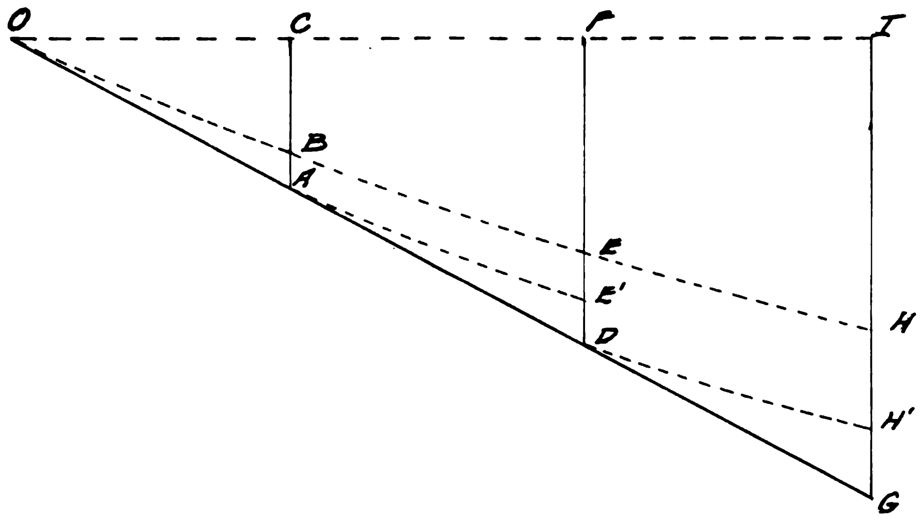
ting the resistances from the velocity required. The resistances thus obtained are the ones at successive points in the path of the car at which the velocities were measured. This mode of test is very satisfactory if the necessary accuracy in time observations can be obtained. Following is a quotation from Mr. Wellington's paper, (T.A.S.C.E.), Vol. 8, 1879, read before the A.S.C.E.: "It is believed that equal accuracy is unattainable by any other mode of test, since it is plain that every step in this process is free from any sensible source of error other than carelessness. The accelerating force (gravity) is uniformly applied and exactly known from formulae, without measurement. This force is necessarily all consumed (1) in overcoming the resistances to be measured, (2) in communicating velocity. The amount of force represented by a given velocity is known by formulae, without measurement, and the velocity itself is exactly recorded by electricity, besides a synchronous record of seconds. Errors from carelessness in computation are always possible, but three checks existed against them . . . . . . Finally, any errors which still occur are not cumulative,

any excess in one resistance causing a corresponding deficiency in the next following and vice versa."

The method to be followed with our apparatus is exactly similar to Mr. Wellington's except that by means of our "tuning-fork chronograph" we are able to read off the time to 1/100 of a second as shown by the results of the calibration of the instrument.

Theory of Method. (According to Wellington)

Fig. #1.



According to the general law of falling bodies, any body descending freely, i.e., without frictional resistance, over any inclined path whatsoever, as "OA", will be moving through space at any point "A", in its path with the same velocity as if it had fallen vertically from "C" to "A". This velocity, for any given fall "h" in feet, is given in feet per second by the well known formula:

V equals $\sqrt{2gh}$ ($\sqrt{}$ indicates square root.) in which "g" equals the acceleration of gravity and is equal to 32.16, (ft. per sec.)

If the body does not descend freely, but is retarded by certain resistances, a certain portion of the accelerating force will be consumed by these resistances instead of communicating velocity to the body; so that the velocity actually acquired may be made a measure of those resistances.

A car descending a known grade as "OA" is under these latter conditions. At any point "A" in its path, it is moving with a certain velocity. When this is known we can determine from the formula above, the corresponding fall,

"CB", through which it must have fallen freely to acquire that velocity. The remainder, "BA", of the distance through which it is known to have actually fallen - because we know the grade "OG" - represents the fall necessary to exactly balance the average resistance in passing from "O" to "A". Then, evidently BA/OC will represent a corresponding rate of grade, which is commonly called the "grade of repose", and this rate of grade in feet per 100, multiplied by 20, i.e., 2,000/100, gives the accelerating force of gravity on the "trade of repose", in pounds per ton (of 2,000 lbs.), which is equal to the total resistance in pounds per ton.

Similarly, if the car continues its motion down the grade to any point "D" and we determine the velocity with which it is moving at that point and the corresponding fall "FE", necessary to give that velocity, the remainder, "ED", of the distance through which it has actually fallen will represent the total amount of fall which has been consumed up to that time, by the resistances encountered from the beginning of motion at "O". But of this distance, "ED", a certain portion, "BA", has

been consumed by the resistances encountered before passing "A". Consequently, laying off "EE' " equal to "BA" on the line "ED" we have "E'D" as the fall or "head", consumed by the resistances between "A" and "D" and E'D/CF equals a new grade of repose between "C" and "F" from which the resistance in pounds per ton can be again determined as above.

From the above, it is evident that the only source of error in such computations lies in the determination of the velocity of motion at the instant of passing the various stations, which is done by the aid of electricity and will be described later.

Resistance of Rolling Stock.

The resistances which come under our consideration are the velocity resistance, the wheel resistance, and the grade resistance.

The first of these, or the velocity resistance, is made up of two factors: namely, the atmospheric and oscillatory or concussive resistances. The atmosphere is due to head and tail and side resistances and it is

almost negligible on a quiet, windstill day. The oscillatory resistance is due to a series of impacts and hence varies as the square of the velocity according to a law of mechanics. These impacts are due to irregularities in the track and to effect of the yielding of the rails and ties in a ballast which is not homogeneous in character nor absolutely uniform in elasticity.

The wheel resistance consists of the rolling friction of the wheels and the journal friction of the axles. The first of these two is more or less intimately connected with the yielding of the rail, while the latter is the force required to turn an axle in its bearings under various conditions of pressure, speed, lubrication and temperature.

The determination of these separate factors can only be made by comparison under different conditions and by close analysis, whereas their sum total can be determined experimentally. To devise a method for this determination is the main purpose of this thesis.

The grade resistance, which enters into all tests, can be computed with mathematical exactness. When the

tractive resistances are computed separately or are assumed to be zero, we merely have to compute the tendency of the wheels to resist rolling down grade or the resistances overcome in pulling them up grade. To determine the grade resistance, consider a car on an incline "fd" as shown in figure.

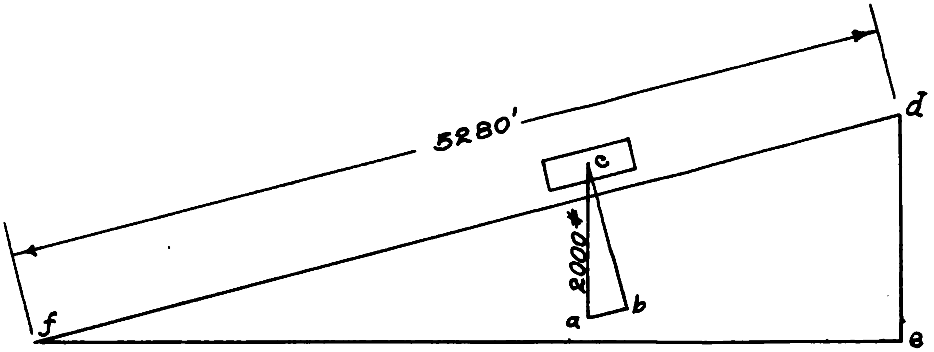


Fig. #2

Let Rg equal grade resistance

" m " rise in ft. in one mile

" ab " force required to move the car up, considering gravity only.

" W " weight of 2000 lbs.

Then ab equals Rg equals 2000 sin. $\overline{acb}$ equals 2000 sin. $\overline{dfe}$

But sin $\overline{dfe}$ equals de/df equals (rise in ft. per mile)/5280.

ab equals Rg equals 2000m/5280 equals 0.38m.

If grade is expressed in percentage, then m_{pc} equals the grade in per cent. m_{pc} equals m/5280 times 100

m equals $5280.m_{pc}/100$

Substituting, Rg equals 2000/5280 times $5280m_{pc}/100$ equals $20m_{pc}$, where Rg equals grade resistance in lbs. per ton considered plus if descending and minus if ascending, and is the amount in lbs. per ton allowed under all conditions where grade enters in. The following table shows the method used in the reduction for grade resistance upon a known grade:

Determination of Grade Effect "G".

(Wingra Park Line, 1,000 ft. East of Regent St.)

Station	Difference in Elevation	Rate of Grade %	"G" in lbs. ton
0			
	0.87	4.35	-87.00
+20			
	0.90	4.50	-90.00
+40			
	0.93	4.65	-93.00
+60			
	0.87	4.35	-87.00
+80			
	0.90	4.50	-90.00
1+00			
	0.98	4.90	-98.00
+20			
	0.96	4.80	-96.00
+40			
	0.94	4.70	-94.00
+60			
	1.05	5.25	-105.00
+80			
	0.97	4.85	-97.00
2+00			

In the derivation of a formula to determine the resistance, let F represent all the force acting upon a car, which shall include grade resistance, the resistance due to curvature and the resistance of straight track.

The other factors mentioned will here be considered as part of the above.

Let F equal plus or minus Rg, plus C, plus f, where

plus or minus Rg equals grade resistance,

C equals curvature resistance,

f equals resistance on straight level track,

d equals distance between successive stations or observation points.

Then Fd equals work done in one interval.

But v^2 equals 2gh

h_1 " $v_1^2/2g$ when h equals velocity height

h_2 " $v_2^2/2g$

and Fd equals $2000(h_2-h_1)$

If d is made constant, i.e., equal to 20 ft.

f equals 100 (h_2-h_1), which is the formula used in figuring the value of f on straight and level track. Upon a track of known grade the grade resistance enters in and (a) becomes (f plus or minus Rg)d equals $2000(h_2-h_1)$.

The above derivation shows the importance of an accurate determination of the velocities at successive equal intervals of space.

Apparatus and Use of Same.

To determine the change of time between stations, the apparatus, consisting of the recording instrument, the automatic triggers, insulated wire and a source of electromotive force was used. The layout is shown on Plate . With all brakes and power turned off, the car on drifting down grade would make contact at each successive trigger and in a manner later explained, the instrument would record the time of passage from trigger to trigger. From the time interval thus measured, the average speed is obtained, the speed distance curve plotted and the speed at any point determined from it. The resistance is then calculated, (according to formula (a)).

An instrument known as the turning fork chronograph, the value of which can only be appreciated by contact, served to measure the time intervals. It was designed by Prof. Pence and constructed under his supervision by the mechanician department of the University. Plates #1- #2show the details of this instrument and the key aids to identify each part.

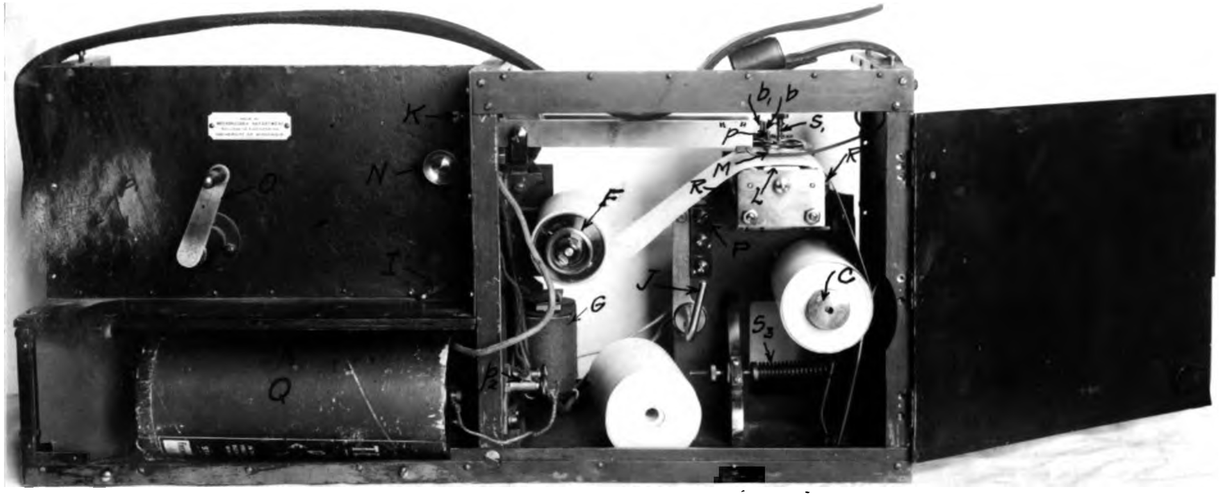


PLATE #1

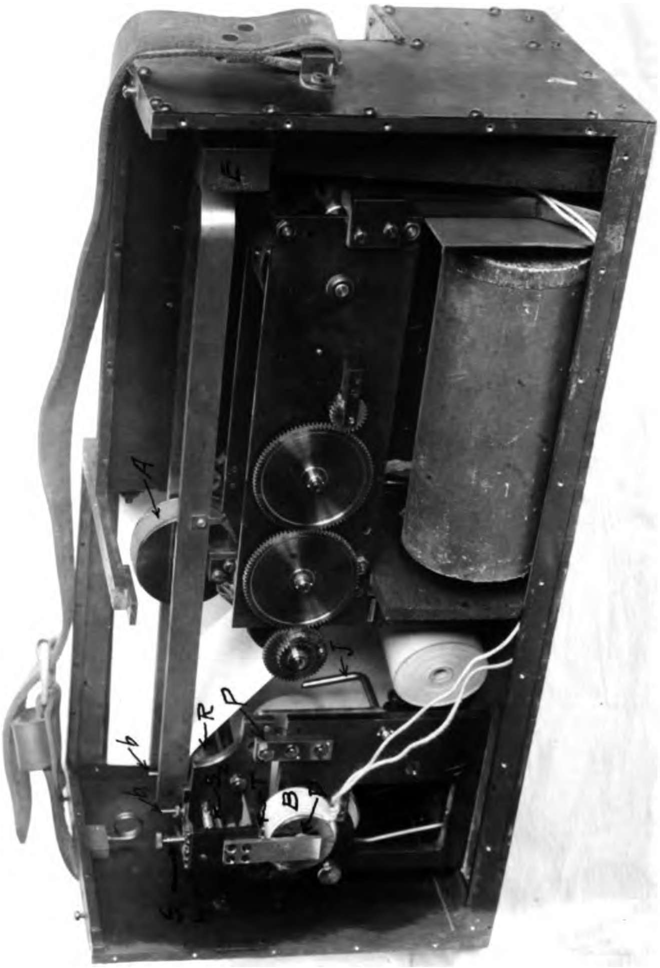


PLATE #2.

Key to Sketches and Photographs.

A - Magnet operating tuning fork.

B - Magnet in track circuit.

C - Brass core for roll of speed recorder paper.

D - Armature for magnet B.

E - Rigid support holding tuning fork.

F - Detachable drum upon which the paper winds.

G - Magnet used in starting clock work electrically.

H - Armature of b.

I - Lever used in starting clock work.

J - Lever lifting riding plate for paper up to pencil points.

K - Switch for circuit b.

O - Winding lever for clock work.

M - Contact maker.

N - Screw closing storage battery circuit and starting vibrations of fork.

L - Aluminum plate upon which brass points bear.

P - Pivot reversing direction of motion of L.

Q - Batteries in circuit B.

R.- Rollers facilitating movement of paper under pencil points.

S_1 - Spring controlling pressure of "p" on paper.

S_2 - Spring controlling mag. of deviation of "p".

S_3 - Spring to regulate speed of C.

T - Thin strip of spring steel connecting armature D with arm W holding "p".

b - Contact point of fork.

b^1 - Dead weight of prong to counterbalance b.

p_1 - Binding posts in circuit A.

p_2 - Binding post in circuit B.

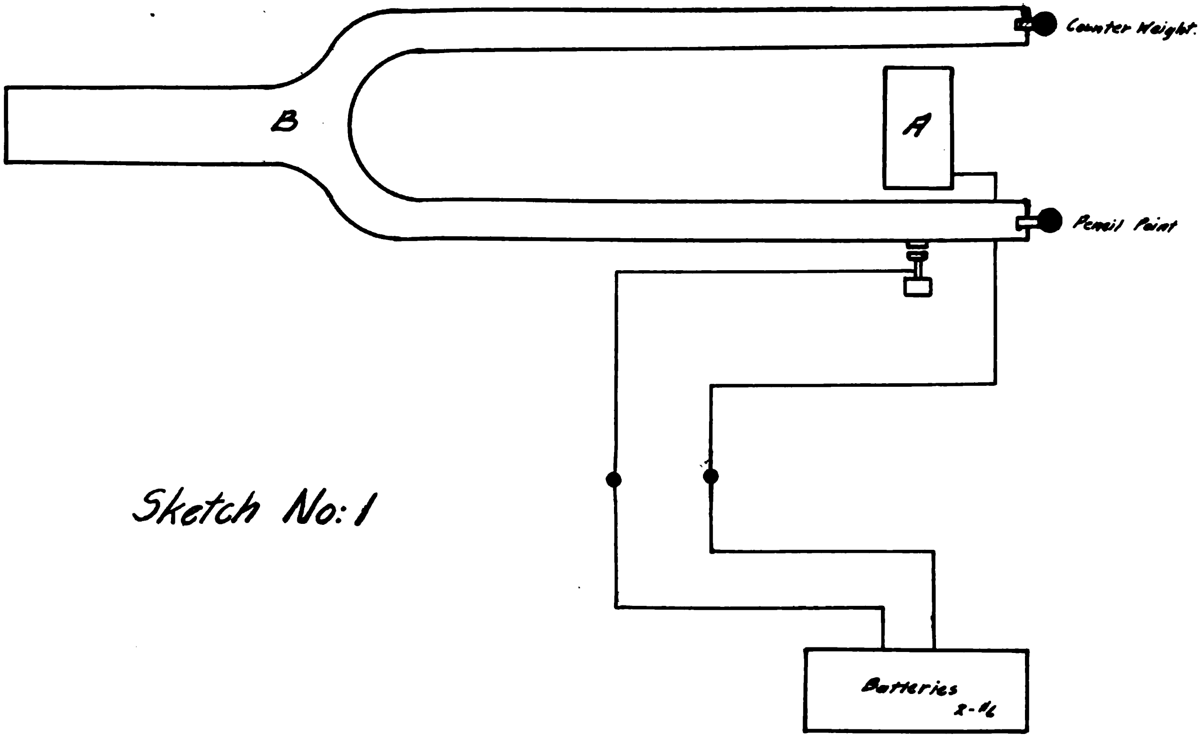
x - Brass point on tuning fork.

"p" - Brass point on arm W controlled by B.

W - Arm holding "p".

A - B.

By means of an electro-magnet A (see sketch #/) the tuning fork (B) is set into vibration, the two #6 dry batteries serving as the source of electromotive force. The vibrations of the fork, set into motion the brass pencil which records the harmonic motion and the



Sketch No: 1

Plan
of
Tuning Fork.

small metal piece which serves as a counterweight to the pencil. As the speed recorder paper unwinds from "C" around the plate L and on to the revolving drum F, the brass pencil instead of drawing a straight line, which it would do if the paper were stationary, produces a harmonic curve each half wave of which, as shown by the calibration of the fork, is equivalent to about 1/100 of a second. The action of the drum is controlled by a clock spring wound by handle O.

By means of the brass point p' operated by the magnet B we are enabled to record opposite the time wave curve, the exact time of passage of the car at each station. The brass pencil "p" is attached to the arm W, which in turn is attached to the armature D moving on the pivot P. When the car wheel strikes each trigger (the development of which is separately discussed), the circuit B is instantly closed. The magnet acts upon the armature, the arm is drawn back and the pencil which previously had been making a straight line, will deviate or make a jog. When the circuit is broken it again falls back to the previous position and its return is governed by the attached

spring.

The entire apparatus is placed along side of the track; the trigger mounted on wood block to the proper height with reference to the flange of the wheel. The contact springs are connected in parallel and the release magnets also in parallel. The one set of dry batteries serves to furnish electromotive force for both circuits, the change from one circuit to the other being controlled by the two switches as shown in Plate #3.

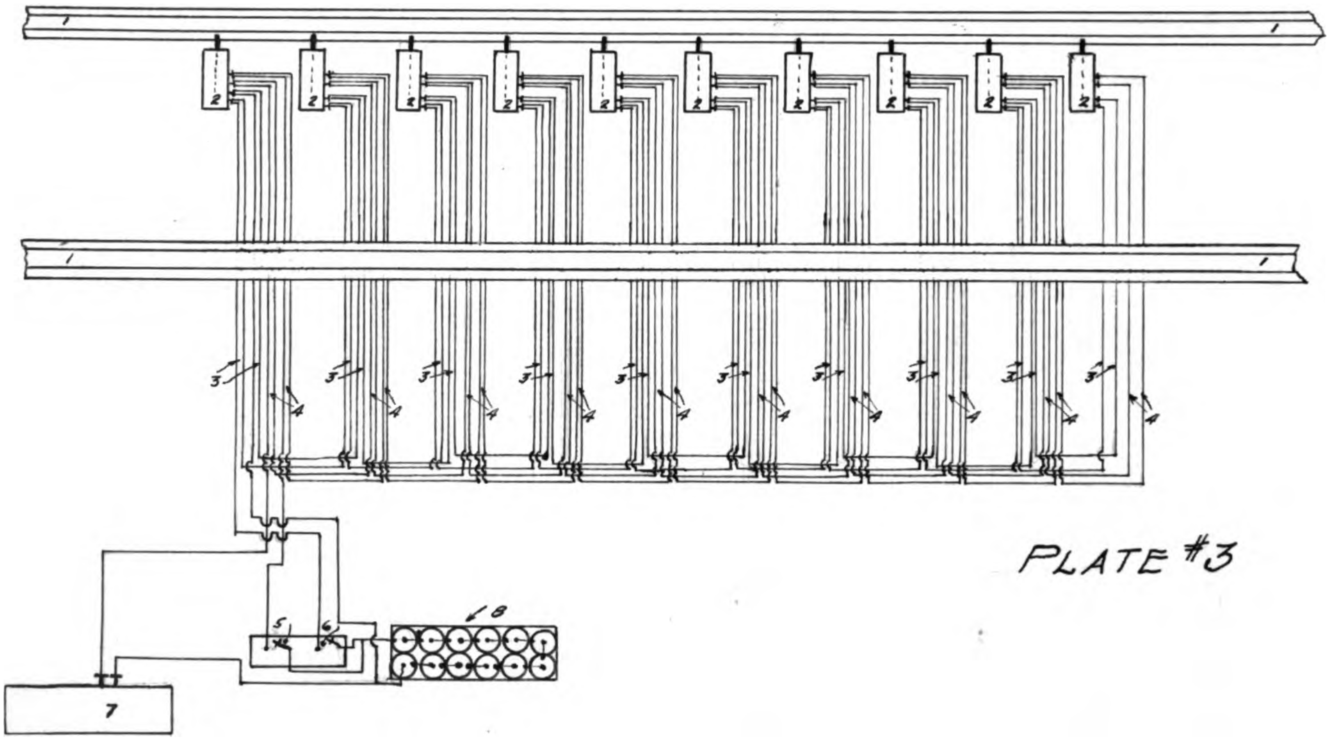


PLATE #3

Plan and Details
of
Track Layout.

KEY TO SKETCH OF
PLAN AND DETAILS OF TRACK LAYOUT

1--Rails

2--Track Triggers at constant intervals.

3--#10 Insulated Wire, connecting magnets of triggers in parallel.

4--#14 Insulated Wire, connecting contact plungers of triggers in parallel.

5--Switch in plunger circuit.

6--Switch in magnet circuit.

7--Recorder

8--Set of twelve #8 dry Batteries connected in series.

Calibration of Recording Instrument.

The recording instrument was calibrated in the Physics Laboratory at two different times. The circuit containing the magnet B was connected up to the clock circuit so that contact was made every second through a telegraph relay. The first run was made previous to the setting of a new brass pencil on the fork and the second immediately after. The results of the two tests differed from each other. It is believed by the writers that this was due to the difference in the weights of the two brass pencils inasmuch as all other conditions were alike in both cases.

The following results were obtained in the run with the new brass pencil, the half vibrations being counted between second intervals:

Second Intervals	Half Vibrations per Second	Second Intervals	Half Vibrations per Second
1	100.5	7	100.0
2	101.0	8	100.5
3	99.0	9	100.5
4	101.5	10	100.5
5	100.0	11	100.5
6	102.0	12	101.0

Average is 100.6 half vibrations or 50.3 full vibrations per second.

Illustrative Calculation of Test.

Although no actual tests were made, this being reserved for a later thesis, the following method of reduction will illustrate the principle previously stated.

Method of reduction of vibrations per second to feet per second: -

Average number of vibrations per second is 50.

Let x = vibrations per 20 ft. of tract from record.

$\frac{x}{20}$ = " " 1 ft.

$\frac{50 \times 20}{x}$ = speed in ft. per second.

$\frac{1,000}{x}$ = " " " " "

Typical reduction in grade: (From Barker and Donohue).

Consider an example from Test # Location between station 0+60 and 0+80 ft. (See page)
The speed as taken from the speed distance curve is 17.0 ft. per second, as shown in column 2. Between 0+80 and 0+100 the speed is 18.1 ft. per second. Squaring the numbers we obtain $(V_1)^2$ and $(V_2)^2$ in column 3. The difference in velocity head (h_1-h_2) is equal to $\frac{(V_1)^2-(V_2)^2}{2g}$

by the law of mechanics. Taking the difference of the squares, column 4 is obtained. In column 5, $(h_1 - h_2)$ is taken equal to the value of $(V_1)^2 - (V_2)^2$ divided by "2g" or $\frac{(18.1)^2 - (17.0)^2}{64.32} = 0.600$.

As explained before the formula for "F" on a grade is $(F \pm G)d = 2{,}000\,(h_1 - h_2)$. By transposing and solving for F, this reduces to $F = G - \frac{2{,}000}{d}(h_1 - h_2)$. Applying this to the values above, we obtained $F = G - 100\,(0.600) = G - 60.0$. As obtained from the grade G is 92 lbs. per ton so "F" the resistance due to tangent track alone is equal to 92.0-60.0 or 32.0 lbs. per ton.

The reduction for resistance on straight level track is similar and is carried out in the same manner.

* * *

Note: The above illustration is taken from a thesis by "Parker & Donohue", written in 1907.

Example from Reduction from

Test No. Location Car # .

Distance from Station 0	Velocity in ft./sec.	V^2	$(V_1)^2-(V_2)^2$	h_1-h_2	F in lbs.per ton.
0					
	11.4	129.96			
20			39.04	0.607	31.30
	13.0	169.0			
40			44.16	0.6875	23.25
	14.6	213.16			
60			42.84	0.666	25.00
	16.0	256.00			
80			50.25	0.781	13.90
	17.5	306.25			
100			47.19	0.734	18.60
	18.8	453.69			
120			100.25	1.560	10.00

* * *

Note: The above example is taken from a thesis by "Parker & Donohue" written in 1907.

THE DEVELOPMENT OF CONTACTS.

In this phase of the work no little difficulty was encountered. The value of instantaneous contacts was fully appreciated and it was here that most of the time was spent. The main idea that had to be kept in view, was to construct the contact-maker in such a manner that the first wheel only of each car would set it into operation and make a record on the synchronous recording sheet.

The sketch of Plate #4 shows the first form of trigger made. It consists of a movable or pivoted lever, so arranged that, when released from its set position, it passes between two brass contact clips and closes the electrical circuit for an instant. This arrangement, mounted on a wooden base, is set on the inside of the track with the lever horizontal and on a level with the top of the rail. (See sketch). To set the apparatus, ready for action, the lever is drawn forward i.e. towards the rail, the spring is stretched and by means of a cord fastened to its end and passing over the top of the rail, the lever is held in position. When the car passes this

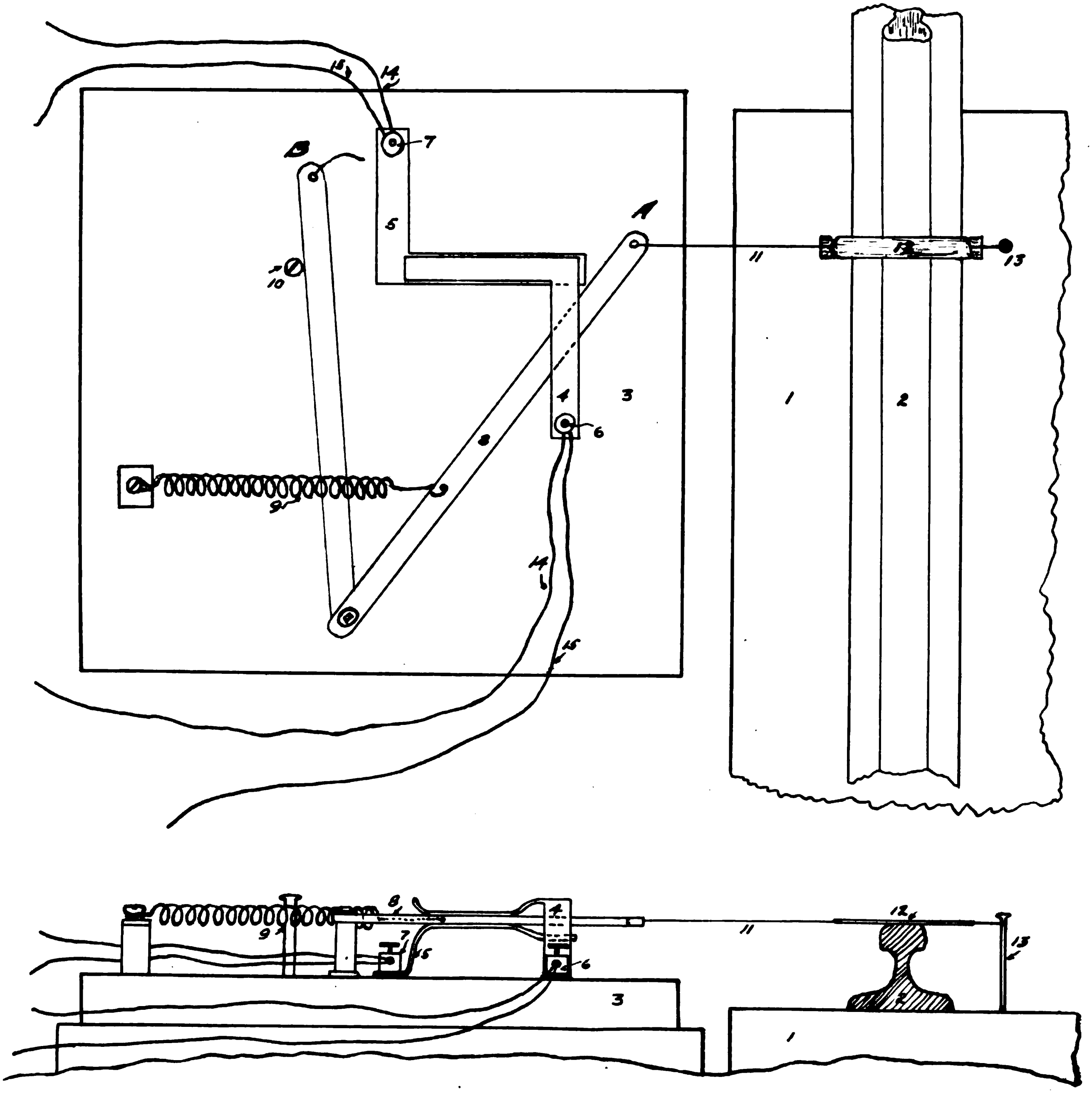


PLATE #4

KEY TO SKETCH OF CONTACT MAKER

1--Wooden tie

2--Steel Rail

3--Base of contact maker

4--Upper Brass Contact Clip

5--Lower Brass Contact Clip

6--Binding Post for upper clip

7--Binding Post for lower clip

8--Brass Lever for making contact with upper and lower clips

9--Steel Spring, acting upon lever

10--Screw for stopping lever, after contact

11--String connecting movable lever to

12--Small piece of glass, joined by string to

13--Iron peg.

14--Insulated Wires, connected to recorder and batteries

15--Insulated Wires, connected to second contact maker.

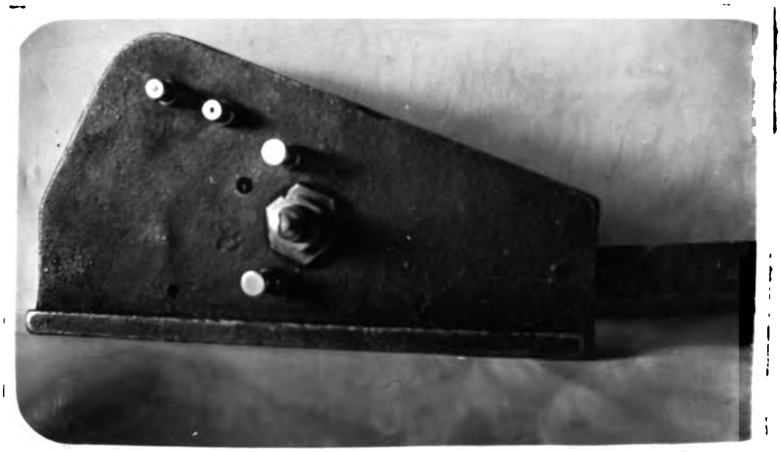
point, the flange of the wheel severs the string, and the tension in the spring causes the lever to fly back to its original position. In moving from "A" to "B" the lever makes contact with the clips and closes the circuit.

In this method much difficulty was expected, by the string not being cut or by the weight of the car pressing it down so hard that it would adhere to the rail and fail to release the lever. To obviate this the cord was replaced by a thin strip of glass. This rested on the rail as shown in the sketch. On account of its brittleness the glass was instantaneously broken, and contact was quickly made. The process of resetting the triggers was however an expensive and a laborious one.

What was desired, therefore, was a trigger which would operate quickly in making contact and which could also be reset without necessitating the use of much time or material, for it was later intended to make tests at places, where the number of cars passing was large and the time between runs short. With this object in view and with the means placed at our disposal a number of designs were made until a trigger apparently satisfactory

was built by the Mechanician Department. View "C" on Plate #5 shows the working details of this trigger after a number of small changes had been made. This new trigger consists of a cast-iron shell (View A, Plate #5) in two parts, inside of which the working apparatus is enclosed, the important part of which is the lever "L" pivoted at "P". When the trigger is set in place the top of "L" is on a level with the top of the rail. The end "A" is pushed down by the flange of the wheel and the end "B" moves up. In its upward movement the lever makes contact at "C". After the wheel has passed, the spring tends to return the lever to its horizontal position, but when the lever is at the point "M" it is held there by a small prop of soft iron "I". This holds the lever above the contact point "C", which is necessary in order to prevent the remaining wheels making a record. Then after all the wheels have passed and the lever is to be released, all that is necessary is to pass a current through the electromagnets "NN" which will attract lever "V" and thus allow lever "L" to drop back to its original position. In the field all these electromagnets are connected up in parallel and when the car has passed over the

PLATE NO. 5

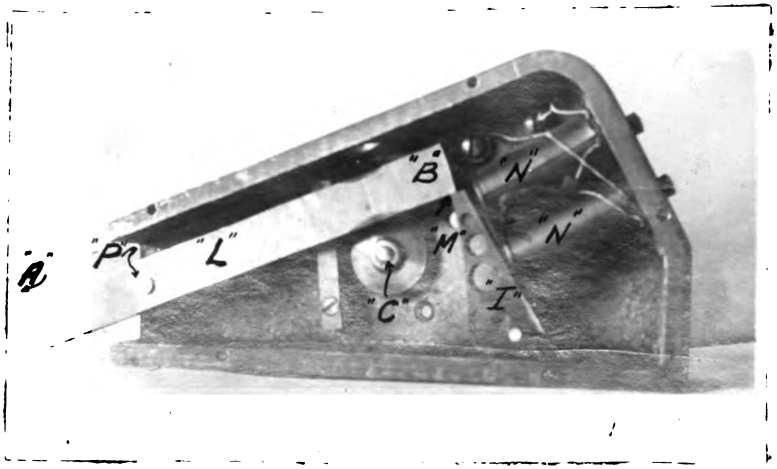


-A-

Case or Shell.

-B-

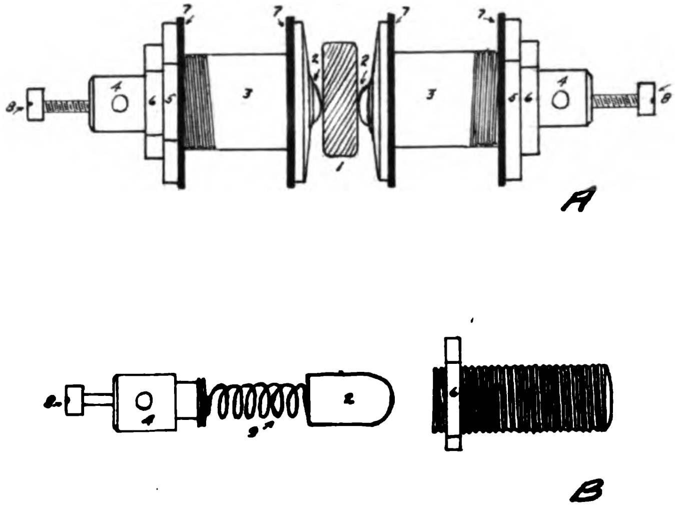
Contact Plungers



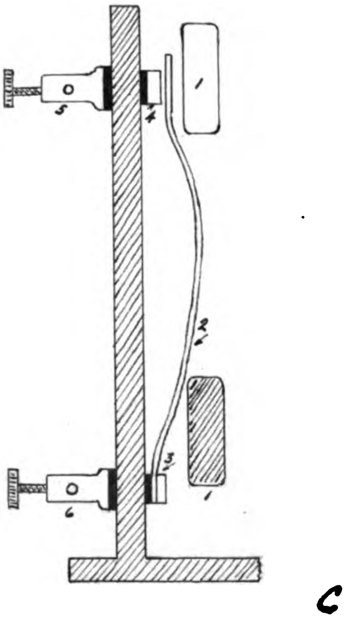
-C-

Inside Details

DETAILS OF CONTACTS.



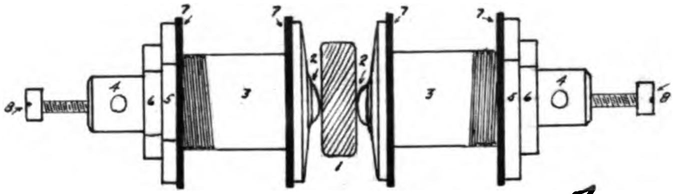
Plunger Type.



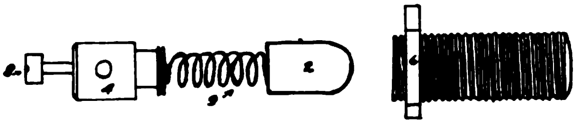
Spring Type.

PLATE #6

DETAILS OF CONTACTS.

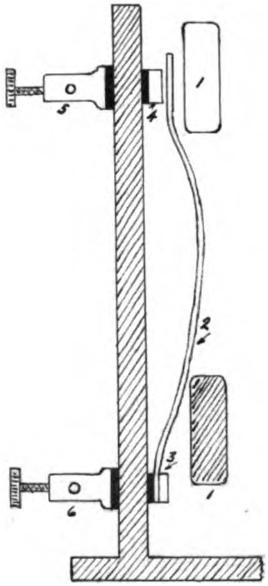


A



B

Plunger Type.



C

Spring Type.

PLATE #6

KEY TO DETAILS OF CONTACTS

A--Plunger Contact

1--Lever of trigger apparatus.

2--Contact Plungers, joined by spring to binding post.

3--Case of plunger and spring--threaded to hold binding post.

4--Binding Post.

5--Nut to bind spring case.

6--Nut to bind post.

7--Rubber washers

8--Screw of binding post

9--Brass Spring of plunger

B--Spring Contact

1--Lever of trigger apparatus

2--Contact Spring

3--Screw holding spring rigid

4--Contact Screw

5--Upper Binding Post

6--Lower Binding Post.

required stretch, the whole apparatus can be gotten ready for the next car by pressing a push button or closing a switch, causing all the levers to fly back simultaneously.

Trouble was encountered at first, because not enough current was used to operate such a large number of electromagnets, but this difficulty was overcome after an additional six #8 Dry Batteries were inserted in the circuit and some of the springs adjusted.

The main difficulty however, was met with in the construction of the contact points, and considerable changes were made in this quarter. The contacts as originally made and the details of which are shown in Plate #5 did not prove satisfactory. They were made as shown and fixed in the side of the shell, from which they were insulated. A short piece of brass tubing was inserted through the cast iron shell and held there by a nut on the outside. Inside of this tubing was another brass case, which by means of its thread could be screwed in or out, thus furnishing an adjustment for the contact surfaces.

The latter case carried the binding post at one end and contained on the inside a ball and spring. The

ball was inserted from the end "A" and held against the shoulder "B" by the spiral spring "S", which at its other end was held by "C".

The spring served as a part of the circuit to carry the current from the binding post to the ball.

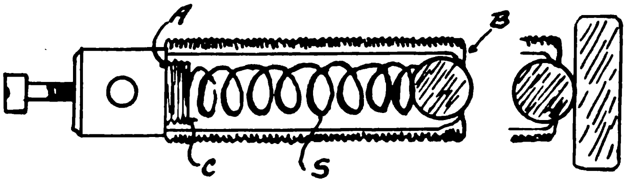
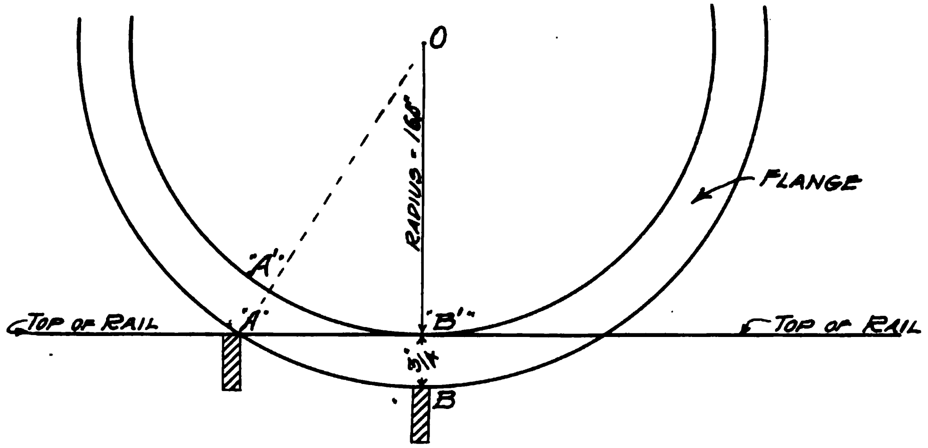


Fig #3.

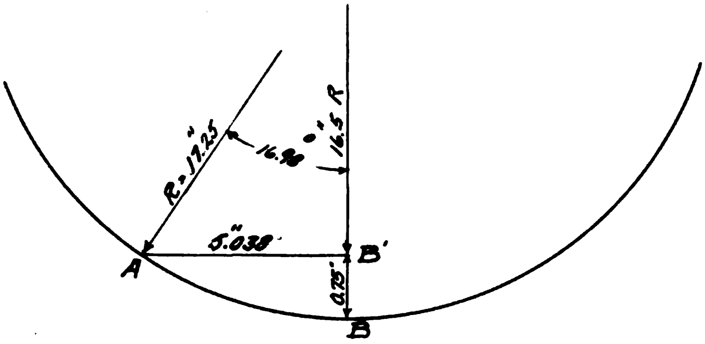
In moving from its lower to its upper position, the lever would touch both balls, close the circuit and the recording magnet would operate. In theory no weak points were apparent in this construction and when the lever was operated by hand, the recording apparatus worked satisfactorily. When the trigger, however was set alongside of the rail and operated by the flange of the wheel, at a fair rate of speed, no contact appeared to be made. Ad-

justments of the posts resulted in nothing better. The failure to act at moderate speeds was attributed to various causes. It was observed that the car wheel would act very quickly upon the lever and that the time interval of making the contact was found to be very short. This was determined in the following manner:

- Determination of Time Interval -



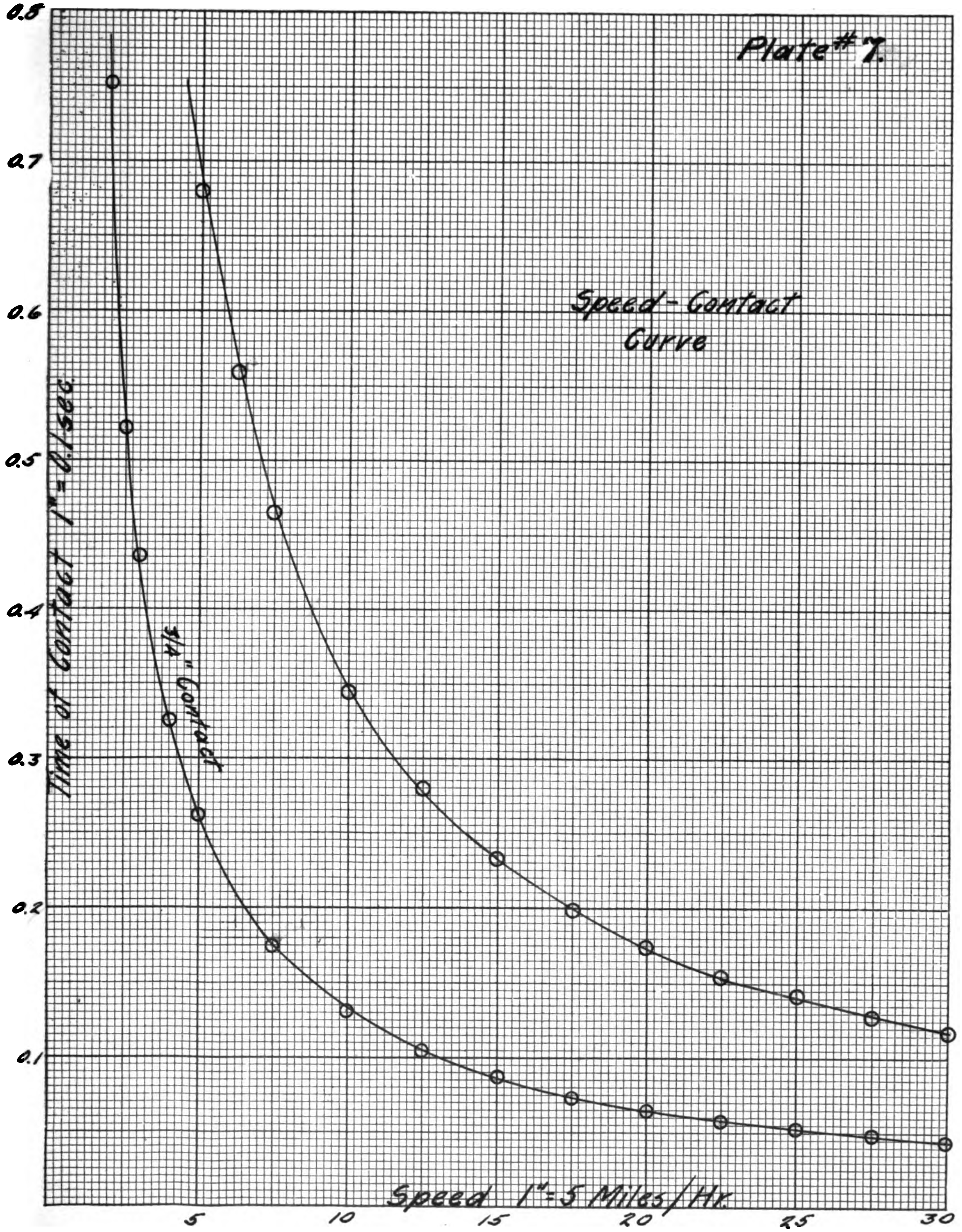
Position "A" shows lever in its horizontal position, when the flange of the wheel first touches it. Position "B" shows it in its lowest position. Hence the time required for the lever to pass from position "A" to "B" will be equal to the time that it takes the car to pass from "B" to "A" along the rail.



From rt. △., AB' was found to be 5.038 inches in length, and angle α = 16.98°. Then arc AB was found to be $\frac{16.98}{360} \times 2\pi \times 17.25 = 5.11$

With a car going at 10 miles per hour it will take 0.348 second to cover 5.11 inches. Hence it will take the lever at the most this time to fly up, or since the lever passes through about 2 inches in this time, but only makes contact for 3/4 of an inch, contact is made for only about 0.131of a second, when the car is going at ten miles per hour.

To see how the contact time factor varied at different speeds a set of values for speeds from 0 to 30 miles per hour were calculated and plotted as shown on Plate #7. The curves show the relation between the speed and time of contact and how the relation changes with a change in the length of contact surface between the balls and the



" See next page "

TABLE OF TIME CONTACT.

Speed in Miles per Hour	Time of Contact for 3/4" surface
0.0	0
2.0	0.7520
2.5	0.5220
3.0	0.4350
4.0	0.3260
5.0	0.2610
7.5	0.1740
10.0	0.1305
12.5	0.1044
15.0	0.0870
17.5	0.0746
20.0	0.0653
22.5	0.0580
25.0	0.0522
27.5	0.0474
30.0	0.0435

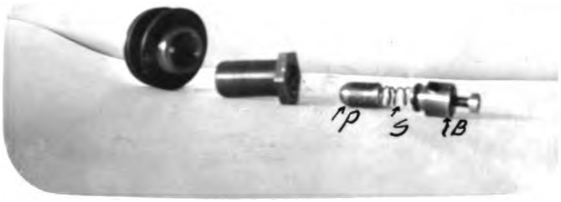
(See curve on previous page).

lever. At high velocities the time interval is very small and due to this time factor it was thought that probably the iron core did not have time to become sufficiently magnetized. Consequently, the winding of the electromagnet was changed so as to give more ampere turns. The change, however, failed to help any.

In the action of the wheel upon the lever the contact was made in such a manner, that the car wheel, rail, lever and balls were brought into the current with the electromagnet of the chronograph; it was thought that probably the return current from the car might affect the trigger by short-circuiting it, but this view was disproved because, in the first place, the contact was made with the car at low velocities and, secondly, the power was shut off when drifting, so there ought to be no return current. The lever however was insulated from the car wheel and its action again tried. The results caused the theory to be abandoned.

The trigger was removed to the shop and its action closely examined. Though the time of contact was very short, still the failure to act could hardly be attributed

to this, because when the circuit was closed by tapping the two ends of the wires together, the magnet responded instantly. Hence it was concluded that the circuit was open at some place and the only place where poor contact was possible was at the contact-balls and the spring that held them. These were replaced by the plunger type of contact, as shown below.

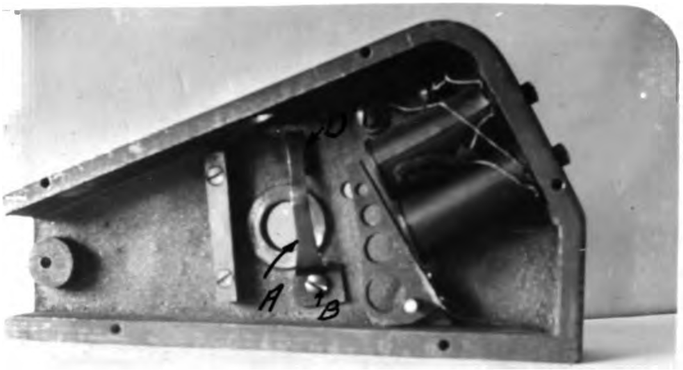


A new brass spring was soldered to both the plunger"P", which was made of brass and the binding-post "B". This helped matters somewhat, but still it was not satisfactory at high speeds.

Next, working along the idea that the mass of iron in the trigger and its case when placed around the path of the current, might because of its inductance affect the passage of the current, another change was made. The lever was made out of brass and the whole thing was mounted in a case made of wood instead of cast iron. The action

being tried again showed the same disappointing results.

All of these changes being for naught, we came back to the conclusion that the contact was too instantaneous. The spring type of contact-maker was therefore constructed as shown below.



This consists of a copper spring "A" placed at one side of the main lever and fastened to a binding post at its lower end "B", whereas the upper end makes contact with another binding post "D", while the lever passes from its lower to its upper position. Thus the surface of contact is increased from 3/4 of an inch to about 2 inches. This change helped materially and worked satisfactorily for low and moderate velocities.

CONCLUSIONS.

In coming to a conclusion, there appears to be only one reason to which the failure to respond at high velocities can be attributed, and that is, the authors believe, the time factor of the electromagnet which operates the recording-pencil. As all other factors which might affect the operation have been disposed of by elimination, this is the only explanation which remains.

The failure surely is not due to the presence of iron in the circuit, which might cause an excessive inductance, because the action of the working parts in a wooden case is exactly identical with that in an iron shell. Also, when a brass lever was used instead of iron lever, no better results were obtained. The character of the shell and lever, therefore, has nothing to do with the action of the contact plungers and lever. Methods of connections used, such as from lever to binding posts or other connections in the circuit, are of such a nature that the current is not hindered in passing through, because, when the lever is moved slowly or at moderate

speed, complete action is produced in the electromagnet of the recorder.

The action of the magnet, when the circuit is made by tapping the wires together, shows the time interval to be the deciding factor and the fundamental cause of failure at high velocities. By varying this means of contact from a slow movement to a very rapid one the action of the electromagnet can be changed until a very rapid movement produces failure. The comparison of these movements with the swift action of the car wheel at high velocities, an action far quicker than that of the hand, makes it appear that the time interval of contact is at fault. This is shown again when a vertical contact spring is used thus increasing the time interval and producing materially better action.

It is therefore necessary to devise an arrangement which will produce immediate or instantaneous contact, hold or keep contact for a short time and then release. A quick contact which corresponds to a quick jog in the record is important, in as much as it is the beginning of each jog between which the time is measured. Hence the importance of an instantaneous contact. With slow-starting contact

appreciable errors will enter in and lag is not desired unless as table # 1 shows, it can be made uniform throughout.

TABLE NO. 1.

Table of Ratios of Difference in Lag to Time Interval.

Station	Lag Constant	Interval	Difference in Lag	Ratio
0	0.01			
		24	0	0
0+20	0.01			
		22	0	0
+40	0.01			
		20	0	0
+60	0.01			
		18	0	0
+80	0.01			
		16	0	0
1+0.0	0.01			
		14	0	0
+20	0.01			
		12	0	0
+40	0.01			
		10	0	0
+60	0.01			
		8	0	0
+80	0.01			
		6	0	0
2+0.0	0.01			

If the lag is therefore uniform and it takes the same time to operate the pencil no error will enter into the results.

On the other hand with a very slow form of contact the time required to move the lever will gradually change from station 0+0 to station 2+0.00 because of the change in velocity.

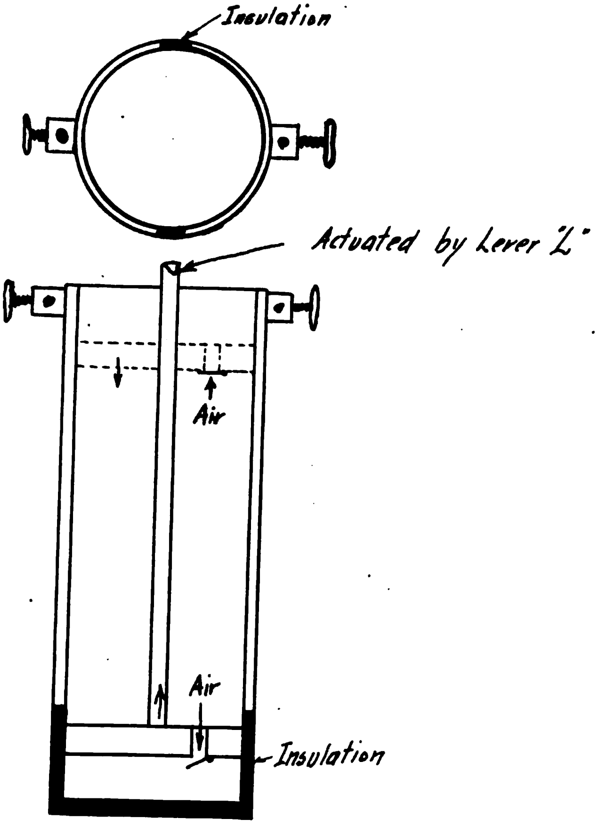
TABLE NO. 2

Table of Ratio of Difference in Lag to Time Interval.

Station	Lag Varying	Time Interval	Difference in Lag	Ratio
0	0.030			
		24	0.002	0.00083
0+20	0.028			
		22	0.002	0.00091
+40	0.026			
		20	0.002	0.00100
+60	0.024			
		18	0.002	0.00111
+80	0.022			
		16	0.002	0.00125
1+0.0	0.020			
		14	0.002	0.00143
+20.0	0.018			
		12	0.002	0.00167
+40.0	0.016			
		10	0.002	0.00200
+60.0	0.014			
		8	0.002	0.00250
+80.0	0.012			
		6	0.002	0.00333
2+00.	0.010			

The ratio thus changes bringing into consideration an increasing per cent of error. Just what the effect

will be, the writers cannot say at the present time. The conclusions however make it appear to them that an instantaneous contact is desired and with this aim in view together with hope of using the present form of trigger the following suggestions are made.



Dash-Pot Suggestion.

SUGGESTIONS.

An arrangement which in the mind of the writers appears the best is a sort of dash pot arrangement shown in the sketch.

A cylinder is made of two semi-circular parts which are insulated from each other. A piston operated by the lever makes contact when the lever passes up the cylinder and a spiral spring brings it back to its original position. The piston is arranged like that in a simple pump, a valve opening when the piston rises and closing when it drops. There the air within is somewhat compressed and tends to slow down the backward movements of the piston which is being pulled back gradually by the spring as the air escapes through the hole.

In conclusion the writers wish to thank Mr. Post of the Mechanician's Department of the University for the aid in suggesting changes. We regret that the peculiar circumstances have made it impossible to actually perfect the working details of the apparatus for all speeds and intend if possible to carry on the work at a later time, for the opportunity along these lines is fully recognized.

Approved by W. D. Pence

Professor of Railway Engineering

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